PhD Physics

Synthesis of Nanostructured Metal Oxides for Development of Highly Sensitive Wearable UV Photodetector Device

Subject: Physics

Faculty: Science and Technology

by

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Title:

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1. Introduction:

Science and technology have altered our daily lives by creating highly intelligent and integrated devices for drug delivery, health monitoring, glucose sensors, and radiation monitors, among other applications[1]. Wearable devices are electronic devices that are designed to live in and on our bodies in various forms[2-7]. These devices should have a high level of performance as well as good mechanical strength and flexibility[1]. Textiles, wristbands, helmets, patches, lenses, and other items that fit well on the body or clothes without restricting users' physical activities were considered "wearable" in the past[3]. This trend has now shifted, and the development of wearable health-related devices has been announced. In this context, a photodetector is one of the devices that may protect humans from skin cancer caused by UV radiation overexposure. This device is made on non-flexible (hard) substrates, making it difficult to use in the fabrication of flexible devices, particularly photodetectors.

Looking at the radiation incident on us, throughout the days we are getting exposed to various types of radiations emitted by the natural source of energy “Sun”. Approximately 9 % of the energy received from Sun is in the Ultraviolet region (400 to 100 nm) which is divided in to three parts: UV-A (400-320 nm), UV-B (320-280 nm) and UV-C (280-100 nm)[8]. Among these three, UV-C rays are blocked by the stratospheric Ozone layer. Whereas, UV-A and UV-B rays are important for human health; for example, for the production of vitamin D. Whereas, exposure to these rays (especially UV-B rays) beyond allowed level may result in acute and chronic health effects on the skin, eyes, and immune system[9]. Moreover, as the wavelength of the UV rays shortens the risk increases and thus we have to be careful about its exposure. This exposure is measured in solar UV Index and is the amount of skin damaging UV radiation reaches the earth's surface. Increasing value of the UV Index implies the greater dose of skin damaging and eye damaging UV radiation. At higher UV Index, the smaller the time it takes before skin or eye damage occurs.

2. Review of Literature and Development in the Subject:

UV photodetectors have piqued the interest of researchers in recent years due to their enormous potential and commercial impact in a wide range of fields, including communications, pollution monitoring, water sterilization, flame sensors, and missile plume detection applications[10]. Si-based UV photodetectors have a fast response time; however, the narrow band gap of Si reduces the sensitivity and selectivity[10,11]. Hence use of wide band gap semiconductors like GaN, CdS, ZnS, CdSe, and ZnO can be thought to be the alternative, where researchers have demonstrated use of these for the detection of UV photons[10-14].

Tao Dong, et.al reported processing, architectures and applications of flexible photodetector based on 2D Materials. The 2D material flexible photodetectors have some interesting applications in UV imaging[15].

Yourong Tao, et.al in this study reported flexible photodetector from ultraviolet to near infrared based on a SnS2 nanosheet microsphere film. The results show that both devices possess a high spectral selectivity, good photoresponse, and good stability[16].

Wei Hu, et.al reported synthesis of perovskite thin films by a vapor-solution method for fabrication of high-performance flexible photodetectors. A flexible PET substrates have been used to grow thin films[17].

Sohail Abbasa, et.al. demonstrated the fabrication and characterization of flexible and transparent photodetector based on conformally grown AgxO/TiO2/ITO layers on PET substrate. Under UV illumination, it showed a high responsivity (323 mA/W) and detectivity (4.2×10^8 Jones).

3. Objectives of Research/proposed Hypothesis

The photoconducting properties of metal oxide thin films synthesized on flexible substrates using the dip coating / spray pyrolysis technique are investigated in this study, as well as the possibility of developing highly sensitive and responsive optoelectronic devices using the deposited film. To achieve the above mention objective this work is made of specific aims;

a. To synthesize metal oxide (MO_x) thin film on flexible substrates using dip coating / spray pyrolysis technique.
b. Characterize using XRD, UV–Vis spectroscopy, Raman spectroscopy, TGA-DTA, SEM-EDS, XPS, etc.
c. To investigate the photoconducting properties of metal oxide samples using dedicated optoelectronic characterization setup. This includes responsivity, detectivity, response (rise/decay) time, sensitivity, gain, etc.
d. TO investigate flexible and wearable photo detection property of the device.
e. To investigate the electronic structure of the film using X-ray photoelectron spectroscopy and understanding the role of its intrinsic properties on charge transport
f. To propose effective wearable photodetector device based on the results and material properties.

4. Methodology to be adopted

This work includes synthesis of MO_x for its viable wearable application in development of optoelectronic device application. This work designed to run on three stages;

The work elements can be broadly categorized under following activities:

Activity 1: Synthesis of metal oxide thin films on flexible substrate via dip coating or spray pyrolysis with various specifications.

Activity 2: Post processing of the metal oxide thin film to achieve physico-chemical integration of the material via temperature annealing / surface passivation.

Activity 3: Characterization of the metal oxide thin film to elucidation of the physical properties of the thin film.

Activity 4: To perform UV photo detection measurements at various intensities of UV light and bending conditions.

Activity 5: Fabrication of a prototype wearable UV photodetector device based on the performance of metal oxide thin films and test its applicability.

5. Importance of study/ Society application:

National status:

Important research outcomes addressing a variety of issues in this field are supported and many are in progress in various National laboratories and universities in the country funded by Government of India. Although it is difficult to summarize the whole effort, a representative cross section of ideas and strategies can be provided as follows: Dr. S. B. Ogale, Dr. Suhas Jejurikar, Dr. Indrani Banerjee, Dr. Abhimanyu Rana, Dr. Rajesh Hyam, Dr. S. S. Islam, Dr. S. H. Husale, etc.

International status:

Flexible device technologies over the past decades has given us devices with powerful capabilities due to advance materials and many researchers across the globe are working to enhance the performance of flexible PDs. International research is just beginning to grow creating an open opportunities for Indian science to take a lead and make a substantial impact. These developments are occurring in the domains of new device concepts. Few impressive examples who flourish the focus of this project are: Dr. Joondong Kim, Dr. S. Sawyer, Dr. Guowei Yang, Dr. U. Jeong, Dr. Z. L. Wang, Dr. Y. A. Zhang, Dr. H. J. Kim, etc. Lots of literature is available on various reputed research journals like: Nature, Science, Advanced Materials, Nano Letters, Advanced Functional Materials, etc.

Significance of the study

Recent reports of World Health Organization (WHO) and GLOBOCAN 2020 indicates that among all cancer cases across the globe, ~ 6.2 % cases are of non-melanoma skin

cancer (due to high UV exposure coming from Sun) and there is constant rise of ~ 2.5 % per year per 1 Lakh cases across the South Asia including India. Even through the mortality rate is low (0.6 %), humans suffering from this decease needs special medical assistance and care.

To prevent our self from this, the UV index monitoring is necessary and for this highly sensitive wearable UV photodetector is required. For fabrication of this UV photodetector a good material is semiconductor based photo-conductors, as its bandgap covers the UV wavelength region. Moreover, their compactness, low cost, and low power consumption makes them more venerable. Among metal oxide (TiO_2, ZnO, SnO_2, etc.) thin film on flexible substrates (polymer or paper) are attractive materials for wearable UV photodetectors.

6. Proposed work Plan/ Formulation and Structure of Study: Year-wise Plan of work and targets to be achieved

First year:

a. Initiate synthesis of pure MO_x film (SnO_2, TiO_2, ZnO, Fe_2O_3, etc.) on flexible substrate using dip coating / spin coating / spray pyrolysis.
b. Study the effect of time / cycle of deposition, temperature and flexible substrate on film morphology.
c. Initiate testing of UV photoconducting properties of pure MO_x film on flexible substrate.

Second year:

a. Optimize deposition technique for synthesis of functional MO_x film on various flexible substrates.
b. Perform extensive characterizations including UV-Vis, XRD, AFM, TGA, SEM–EDS and XPS to know the structural, morphological, optical and electronic properties of MO_x thin film.
c. Initiate making device structure by putting metal contacts.

Third year:

a. Perform real time photodetection measurement on the fabricated device.
a. Estimate the photodetector parameters like responsivity, detectivity, sensitivity, photoresponse time, efficiency, nose equivalent power, gain, etc.
b. Initial testing of flexible device properties of MO_x thin film.
c. Start publishing research papers

Fourth year:

a. Review the status of progress during the first two years and take appropriate steps towards the most effective utilization of the knowledge, facilities and experience during the remaining duration **.**

b. Continue to analyze the data obtained and proceed with publications / petenting as appropriate.
c. Prepare thesis for submission**.**

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